CURRENT FITTING PATTERNS OF DIFFERENT HEARING AID TECHNOLOGIES IN SCHOOL-AGED CHILDREN THROUGHOUT THE STATE OF OHIO

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ABSTRACT

The present study sought to identify the current hearing aid technology fitting patterns of school-aged children throughout the state of Ohio in order to learn what types of hearing aid technology these children are wearing, to determine what the fitting patterns of these different hearing aid instruments are in various regions throughout the state and to compare Ohio state statistics to national sales statistics reported from hearing aid manufacturers throughout the United States. The previously stated objectives were accomplished by contacting educational audiologists working in both Ohio school systems and Special Educational Regional Resource Centers (SERRC Centers) located throughout the state of Ohio. These educational audiologists were asked to complete a survey regarding the hearing aid technology currently worn by children in their caseloads.

Survey results from the present study showed that for the state of Ohio as a whole conventional analog technology is the most commonly fit hearing aid technology followed by digitally programmable analog hearing aid technology and then fully digital signal processing hearing aid technology. Furthermore, data analysis testing comparing the Ohio state hearing aid technology statistics obtained from this study to the national hearing aid sales statistics reported from the hearing industries association showed that a significant difference exists between the hearing aid technology fitting pattern identified for the state of Ohio and the hearing aid technology fitting pattern identified for the

United States. The data results obtained from this study suggest that children who are utilizing hearing aids throughout the state of Ohio are greatly lagging behind the nation in technological advancement as it pertains to hearing aid amplification.

Dedicated to my family.

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CHAPTER 1

INTRODUCTION

There are many different hearing aids available on the market today. These hearing aids range in technology from basic analog instruments to high end fully digital signal processing instruments. Various studies have been performed concerning these amplification devices on the adult population; however, there has been limited research conducted regarding these amplification devices on the pediatric population. The lack of research relating to this specific population is problematic considering that audition is an essential part of a child's development.

Currently, many clinical audiologists work with the pediatric population. Furthermore, many of these audiologists have their own rationale for choosing the types of hearing aids they fit on children. Some of these fitting decisions are shaped by a variety of factors including funding issues, parental preference and personal fitting philosophy. With so many different hearing aids to choose from and with so many different factors playing a role in which hearing aids are chosen for hearing-impaired children, the possibilities are endless as to what types of hearing aids audiologists are fitting on their pediatric patients.

The present study addresses hearing aid technology worn by school-aged children throughout the state of Ohio. During the course of the 2002-2003 school year, educational audiologists throughout the state of Ohio were contacted. These audiologists were asked to provide information regarding the number of children in each of their school districts who were fit with one of three different types of hearing aid technology (conventional analog, digitally programmable analog and fully digital signal processing technology). The purpose of this study was to identify the current hearing aid technology fitting patterns of school-aged children throughout the state of Ohio in order to learn what types of hearing aid technology these children are wearing, to determine the fitting patterns of these different hearing aid instruments in various regions throughout the state and to compare Ohio state statistics to national sales statistics reported from all hearing aid manufacturers.

CHAPTER 2

LITERATURE REVIEW

The Importance of Hearing in Children

A hearing loss of any type, degree or configuration can present a significant barrier to an infant or child's ability to receive information from their listening environments (Flexer, 1999). According to Northern and Downs (2002), hearing loss is a handicap; if left undetected and untreated, hearing loss in children can lead to delayed speech and language development, social and emotional problems, and possible academic failure. Therefore, it is imperative that children who are hearing impaired are not only appropriately amplified, but that they receive the necessary audiologic and educational intervention required to meet their individual needs.

Characteristics of Hearing Loss

The effect that hearing loss has on children depends on several different characteristics. These characteristics include the type of hearing loss, the degree and configuration of the hearing loss, and the age of onset of the hearing loss. All three of these characteristics not only aid audiologists in choosing appropriate hearing devices, but they also play a significant role in the programming of hearing instruments and in determining the need for further intervention.

The first characteristic of hearing loss is the type of hearing loss. There are three different types of hearing loss; conductive, sensorineural, and mixed. A conductive hearing loss is a loss in hearing that occurs when there is interference in the transmission of sound from the external auditory canal to the inner ear. Conductive hearing loss attenuates the incoming signal without adding any distortion; because there is no distortion added to the signal, children with conductive hearing impairments typically perform well when utilizing amplification. A sensorineural hearing loss is a loss in hearing that occurs when damage has been sustained by the sensory end organ or hair cells located within the cochlea, or problems related to the auditory nerves in the higher pathways. Sensorineural hearing loss not only attenuates the incoming signal, similar to a conductive hearing loss, but it also adds distortion to the signal due to impaired processing in the cochlea or beyond. Therefore, children with sensorineural hearing loss who utilize amplification typically experience some speech understanding difficulties and will often have trouble hearing in listening environments where background noise is present. The final type of hearing loss is a mixed hearing loss. A mixed hearing loss includes the presence of both sensorineural and conductive hearing losses, and therefore presents with a combination of the problems associated with each of the two previously mentioned types of hearing loss.

The second characteristic of hearing loss is the degree and configuration of the hearing impairment. Hearing loss can range in severity from slight to profound and can have many different accompanying configurations. As expected, a slight or minimal hearing loss, ranging from 16 to 25 dB HL, tends to minimally affect a child's hearing and communicative abilities, while a profound hearing loss, 91 dB HL or greater, significantly affects a child's hearing and communication abilities. Furthermore, a "rising" configuration, being of greater severity in lower frequencies than higher frequencies will impair a child's perception of lower pitched vowel sounds, while a "sloping" configuration, with more sensitive hearing in lower frequencies than higher frequencies will impair a child's perception of higher pitched consonant sounds. This skewed perception of auditory information, no matter how slight the hearing impairment is, will greatly impact a child's understanding of speech, which will place a child at significant risk for developing language learning problems in the future.

The final characteristic of hearing loss is the age of onset of the hearing impairment and the age at which the hearing impairment is identified and treated. Hearing impairments in children can be classified into two different categories, congenital and acquired; relative to when in the child's life the hearing impairment first occurs (Flexer, 1999). Congenital hearing impairments occur before birth, while acquired hearing impairments occur after birth (Flexer, 1999). Generally, the earlier a hearing impairment occurs in the developmental process, the more the hearing impairment interferes with language, learning, and enrichment of auditory brain function, unless the child receives effective intervention (Flexer, 1999). A later occurring hearing impairment certainly requires intervention, but the consequences of an acquired hearing impairment are not as pervasive if the child already has established a relatively sophisticated linguistic system and rich neural connections in the auditory cortex (Flexer, 1999).

Contrasting Hearing Loss in Children and Adults

It is imperative for educators, audiologists, physicians and parents to understand that children who are hearing impaired differ greatly from adults who are hearing impaired. Children who are hearing impaired require individualized audiologic test protocol, specialized methods of amplification programming, and more detailed and informative counseling for both parents and educators.

There are many different issues that audiologists must be aware of when testing children as opposed to testing adults. For example, infants and small children have higher (10 – 25 dB) behavioral detection thresholds for pure tones than do adults. (Stelmachowicz, Hoover, Lewis, Kortekaas, & Pittman, 2000). Therefore, audiologic test batteries should consist of not only pure tone air and bone conduction testing, but also speech recognition threshold (SRT) and word recognition testing. Furthermore, modifications of pure tone testing such as Visual Reinforcement Audiometry (VRA) and Conditioned Play Audiometry (CPA) are often warranted based on a child's age and cognitive ability. Speech and language abilities can be limited in children, consequently restricting the amount of information an audiologist can obtain during a testing period. Therefore, audiologists should utilize speech tests developed for children with limited expressive language skills such as the WIPI (The Word Intelligibility by Picture Identification) (Ross & Lerman, 1970) or the NU-CHIPS (Northwestern University Children's Perception of Speech) (Elliott & Katz, 1980) tests. Finally, because children's attention spans can be quite short, some physiologic rather than behavioral testing should be performed in order to verify information regarding a child's hearing acuity. Such testing may include tympanometry, acoustic reflex threshold testing, otoacoustic emission testing and in some cases, auditory brainstem response (ABR) testing.

There are many different issues that audiologists must account for when fitting children with amplification in contrast to hearing aid fitting protocols with adults. The first issue is the style of the amplification device. Most audiologists who treat the pediatric population agree that the most appropriate style of hearing aid to be fit on a child is the behind-the-ear hearing aid. This style is generally fit on children based on its durability, its ability to incorporate telecoils for telephone usage and Direct Audio Input (DAI) for FM system compatibility, and because it is more cost effective to purchase new ear molds for behind-the-ear hearing instruments than it is to re-case custom products when children's pinnas and ear canals change shape as they grow.

Once hearing instruments are selected, the second consideration that audiologists must account for when fitting children with amplification is the frequency response of the instrument. Because children, unlike adults, are sometimes unable to accurately describe a hearing instrument’s sound quality and amplification quantity, certain precautions are usually taken to ensure the proper fit of the hearing instruments. Such precautions include the use of a prescriptive formulae to determine target gain requirements relative to the patient’s auditory thresholds, utilizing probe microphone measurements permitting the assessment of the aided frequency response and output levels of the amplified signal intensity at the child’s eardrum, and performing aided warble tone and speech testing in the sound field in order to measure a child’s functional performance utilizing the amplification (Northern & Downs, 2002). When all three audiologic methods discussed previously are utilized properly in the hearing aid fitting process, audiologists can be certain that the hearing aids being fit on their pediatric patients are appropriate for each child's specific hearing impairment.

The last consideration that audiologists must attend to when fitting children with amplification is how the families of the children with hearing loss are counseled. According to Northern and Downs (2002) the importance of parental involvement in the habilitation process of children with hearing loss is crucial to the child's success with amplification. Unfortunately, there are no specific guidelines that can always be followed when dealing with parents of children who are hearing impaired, because parents are unique and have backgrounds, attitudes, and needs that must be dealt with on a very personal basis (Northern & Downs, 2002).

Regardless of how individualized counseling sessions need to be for families of children with hearing loss, there are basic issues that must be discussed and understood universally. The first and most important concept is that the family accepts and understands the child's hearing impairment and the role that the hearing loss will play in that child's life (Northern & Downs, 2002). The second concept is that the parents understand how imperative it is for their child to utilize their hearing aids correctly on a daily basis both at home and at school, and for those families to have appropriate expectations about the amplification devices used by the child (Northern & Downs, 2002). The third and final concept is that the family must show responsibility, interest and motivation for all medical and educational issues related to their child.

Based on the previously stated information it is easy to see that children with hearing loss and adults with hearing loss differ tremendously in many different ways. Children with hearing loss hear and process auditory information differently, they require special considerations during audiologic testing, amplification fitting and rehabilitative counseling, and most importantly they require consistent and continuous audiologic and educational services to ensure their successful growth and development into adulthood.

Communicative, Educational, and Psychosocial Effects

A hearing loss can have many adverse effects on a child's communicative, educational and emotional development. A hearing impairment can delay speech and language acquisition, it can cause significant deficiencies in the semantic, syntactic and pragmatic components of language, it can negatively impact a child's educational achievement and it can also have severe affects on a child's emotional well-being. Because there are so many negative consequences that accompany an undetected or untreated hearing loss, it is important for both audiologists and educators to be aware of these adverse effects when working with the pediatric hearing-impaired population.

One of the most important milestones in any child's development is the acquisition and production of spoken language (Northern & Downs, 2002). Language allows individuals the ability to express thoughts, needs and feelings and it is the means by which they are able to receive and comprehend the thoughts, needs, and feelings of others (McConnell & Liff, 1975). Although it is language that plays a vital role in a child's educational and developmental achievement, the successful acquisition of language is highly dependent on an adequately functioning auditory system (Northern & Downs, 2002).

Elliot and Elliot (1964) were the first researchers to confirm that the human cochlea has normal adult function after the 20th week of gestation. Therefore, the beginnings of language learning are thought to occur at birth and possibly before birth. Evidence of this language learning is expressed by normal-hearing infants in a general order of succession of speech development beginning with the onset of cooing, laughter, and reduplicated babbling followed by vocal play and ultimately single-word production (Northern & Downs, 2002).

In comparison to the normal-hearing infant, an infant who has hearing loss does not exhibit the same sequence of speech and language learning or production. In 1986, Stoel-Gammon and Otomo performed a study comparing normal-hearing children with children (ages 4 – 28 months) who have hearing loss. Phonetic transcriptions of babbling samples were used to compare speech and language acquisition of the two groups of children. Results from this study showed the normal-hearing group to have increased consonantal repertoires and multisyllabic utterances with age in contrast to the group with hearing loss. The results of this study lead to the hypothesis that the inability of children with hearing loss to hear their own vocalizations prevents them from the acoustic self-stimulation that encourages additional babbling and the consequential expansion of new speech sounds (Northern & Downs, 2002).

One of the most frequently debated theories regarding hearing loss in children revolves around the hypothesis that there is a critical period in development when auditory signals will be optimally received and utilized for important prelinguistic activities, but once this stage has passed; the effective utilization of these signals gradually declines (Northern & Downs, 2002). An opponent to this optimal period hypothesis was Bench (1971), who stated that if there was a method developed to change the effects of a hearing loss in a child back to normal, then the so-called critical period is not critical after all. In support of Bench's theory, recent research has revealed promising retraining possibilities, beyond critical periods of time, which are thought to be due to the plasticity of the brain (Northern & Downs, 2002).

A recent study of critical periods was performed by Yoshinaga-Itano, Sedey, Coulter, and Mehl in 1998. In this study, the receptive and expressive language abilities of 72 deaf or hearing-impaired children whose hearing losses were identified by 6 months of age were compared with 78 children whose hearing losses were identified after the age of 6 months. All of the children utilized in this study had bilateral hearing impairments ranging from mild to profound in severity and all of these children received early intervention services within an average of 2 months after identification. The results of this study showed that children whose hearing losses were identified by 6 months of age demonstrated significantly better language scores than children identified after 6 months of age. Results from this research support the critical period theory, and demonstrate the importance of early intervention.

Hearing loss not only impairs the rate of language acquisition in children as discussed previously, it also negatively impacts how children use and understand language. In general, language can be broken down into three basic components; semantic content, syntactic form, and pragmatic use, and all three of these language components can be negatively affected by the presence of a hearing loss.

The first component of language that can be affected by the presence of a hearing loss is semantic content, which is the element of language that concerns meaning (Hull, 2001). Semantics represents how words in language are related to other words in sentences that represent relationships between people, actions, and objects (Hull, 2001).

During the first two years of a child's life, parents serve as conversational models for their children by utilizing short, simple, interesting, redundant, and comprehensible sentences. They often will use nonverbal cues (pointing, positioning and visual gaze) and suprasegmental features (intensity, pitch, intonation and duration) when speaking to their children in order to emphasize the meaning of words in complete sentences (Hull, 2001). Unfortunately, hearing-impaired children are often unable to accurately hear words and contextual cues in conversational or instructional situations, which can result in their misunderstanding of words and their intended meanings.

The second component of language that can be affected by the presence of a hearing loss is form, which includes the syntactic, phonologic, and morphologic features of language (Hull, 2001). While syntax composes the grammatical rules one applies to alter words and arrange them into sequential, meaningful sentences in an orderly fashion (Pollack, 1985), morphological inflections and single sound phonemes also contribute to the enhancement of language meaning (Hull, 2001). Consequently, children with hearing loss are often unable to accurately hear the syntactic, phonologic, and morphologic features of language when demonstrated by their linguistic models, which often results in their inability to correctly use them in their own expressive language.

The last component of language that can be affected by the presence of a hearing loss is the pragmatic use of language, which involves the contextual appropriateness, functionality, and intent of language (Hull, 2001). Pragmatic use is shaped by a child's perception and learned understanding of the first two components of language discussed previously, semantics and syntax. Therefore, children with hearing loss who are unable to accurately hear and understand language correctly will also have difficulties in appropriately expressing their thoughts to others with whom they are engaging in conversation.

Aside from the negative effects hearing loss has on speech and language acquisition and development in children, it can also create significant educational challenges in classroom environments. The recommended noise level in a typical classroom is 40-50 dBA or lower, a signal-to-noise ratio of +15 dB, and a reverberation time of lower than .4 s (Berg, Blair, & Benson, 1996; Ross et al., 1991). In comparison, the typical classroom in the United States of America has an average noise level of 40-60 dBA, a signal-to-noise ratio of +1 dB to +5 dB, and a reverberation time ranging from .3 s to greater than 1.5 s (Berg, et al., 1991). These increased noise levels, adverse signal-to-noise ratios, and excessive reverberation times can significantly impact both normally hearing and hearing-impaired children's speech understanding abilities in classroom environments with poor acoustics creating unnecessary educational challenges.

In a study performed by Knecht, Nelson, Whitelaw and Feth in 2002, background noise levels and reverberation times in various unoccupied classrooms located in central Ohio were measured. Results from this study were compared with the limits recommended by the American National Standards Institute standard for acoustical characteristics of classrooms in the United States (ANSI S12.60-2002)). The results from this study indicated that most classrooms evaluated were not in compliance with ANSI noise and reverberation standards, creating potential adverse listening conditions for students who attend classes in these particular classrooms. Therefore, the results of this study are consistent with the previously mentioned national statistics reported from Berg, Blair, & Benson (1996) and Ross et al. (1991).

There are several negative effects that poor classroom acoustics will have on children and their educational achievement. For school-aged children, behavioral observations include poor achievement in language-based subjects (reading and English), poor performance on language-based tests, and decreased classroom participation with both peers and classroom teachers (Adams, 2000). These behaviors often result in poor academic achievement and in some cases failure in lower grade levels (Ross et al., 1991).

The final negative consequence that a hearing loss may have on a hearing-impaired child is its effect on a child's emotional well-being. While it is evident that every child is different and that every child with a hearing impairment may experience different difficulties, the likelihood of behavioral problems has been shown to increase when the presence of a hearing loss in a child exists. A study performed by Davis, Elfenbein, Schum, and Bentler, (1986) reported that children with sensorineural hearing losses ranging in severity from mild to severe typically show more behavioral problems and are also characteristically more aggressive than other children of the same age without hearing loss. These children were also reported to "express physical complaints" and have more "social problems involving isolation and adjustment to school" than their non-hearing impaired peers (Davis et al., 1986).

In conclusion, a hearing loss can present a significant barrier to an infant or child's ability to receive information from their various listening environments (Flexer, 1999). Furthermore, if a hearing loss remains undetected and untreated in children, it may lead to delayed speech and language development, social and emotional problems, and possible academic failure. Therefore, as previously stated, it is imperative that hearing impaired children are not only appropriately amplified, but it is also important that they receive the necessary audiologic and educational intervention required to meet their individual needs.

Amplification Options

There are many different types of hearing aids available on the market today. These hearing aids range in technology from the conventional analog instrument to the fully digital signal processing instrument. Given the many varieties of instruments available to consumers, the different characteristics of these amplification devises along with their many advantages and disadvantages are discussed below.

Conventional Analog Instrument

The basic components of a conventional analog hearing aid include a microphone, an amplifier, and a receiver. The function of these three hearing aid components is to convert acoustic signals picked up from the environment into electric voltages, amplify those electric signals, and then convert them back to an acoustic form ready to be delivered to the user's ear. This conversion of acoustic energy into electric energy in an analog hearing aid begins when the hearing aid microphone picks up pressure variations produced by moving molecules in the environment (Hussung & Hamill, 1990). These pressure variations cause the diaphragm of the hearing aid microphone to have an analogous motion therefore changing acoustic signals into electric signals (Hussung & Hamill, 1990). Once the acoustic signals are converted into electric signals, they are then sent to the hearing aid amplifier where they are amplified. Following amplification the alternating current is then sent through a coil, wound around the armature of the electromagnetic receiver, to the receiver diaphragm (Valente, Hosford-Dunn, & Roeser, 2000). The receiver diaphragm then moves back and forth, producing compressions and rarefactions having amplitude and frequency proportional to the variations in electrical current from the amplifier (Valente et al., 2000). In this manner the receiver converts electrical energy into acoustic energy ready to be delivered to the ear canal of the hearing aid user.

Aside from its analog signal processing, the conventional analog hearing aid is often identified by both a manual volume control and potentiometers. The volume control functions to allow the hearing aid user to manually adjust the gain of the hearing aid. Potentiometers allow clinicians to adjust various electroacoustic characteristics of the hearing aid, such as the frequency response, the output level and the compression characteristics of the hearing aid (Hussung & Hamill, 1990). Potentiometers offer the clinician flexibility in adjusting the hearing aid to better meet the needs of the listener.

Today, conventional analog hearing aids typically utilize two basic forms of amplification. These two types of amplification are commonly known as linear and nonlinear (or compression) amplification. Linear amplification applies the same gain to all input levels. This creates a one-to-one relationship between the input of the hearing aid and the output of the hearing aid. This one-to-one relationship continues until the output level reaches the saturation point (OSPL 90) of the hearing aid. Once the saturation point is reached, the signal is then modified by a process called peak clipping (Dillon, 2001). Peak clipping is a very simple and effective method of output limiting; however, when the peaks of the signal are clipped off distortion occurs and thus compromises the sound quality of the hearing aid (Dillon, 2001).

Nonlinear amplification utilizes a feature called compression, which compresses sounds to fit within the dynamic range of the hearing aid user (Mendel, Danhauer, & Singh, 1999). This type of amplification does not provide the one-to-one correspondence between input and output at all input levels as seen with linear amplification (Mendel et al., 1999). Instead, the gain of the hearing aid varies with changes in input level; as input levels increase, the gain of the hearing aid decreases.

There are primarily two types of compression most commonly used in hearing aid circuits, compression limiting and wide dynamic range compression. Compression limiting amplification is characterized by a high knee point (the point at which compression begins) and a high compression ratio (the ratio of change in the output of a hearing aid that results from a change in the input level of a hearing aid) (Valente et al., 2000). With this type of compression, linear amplification (1:1 ratio) is observed until a knee point is reached and then above the knee point input signals can be severely compressed by high compression ratios (4:1 to more than 10:1) (Valente et al., 2000). Compression limiting was developed as an alternative to peak clipping offering amplification with significantly less audible distortion of the sound signal.

The second form of compression most commonly used in hearing aid circuitry is wide dynamic range compression. Wide dynamic range compression (WDRC) is characterized by both a low knee point and a low compression ratio (Valente et al., 2000). With WDRC, greater amplification is given to low-intensity signals than to medium-intensity signals and little or no amplification is given to high-intensity signals. This form of compression attempts to mimic the amplification provided by normal undamaged outer hair cells in the cochlea (Mendel et al., 1999). As with compression limiting, an advantage of WDRC amplification over linear amplification is that the sound wave is compressed rather than clipped, which results in less audible distortion for the hearing aid user (Dillon, 2001).

The advantage to analog signal processing is that it is a familiar and well-understood type of signal processing that is relatively inexpensive (Katz, 2002). The disadvantages to this type of signal processing are that it does not allow precise control of the electroacoustic characteristics and advanced forms of signal processing for noise reduction, feedback control, and comfort. Thus, the technology is quickly becoming outdated for the management of acoustic signals (Katz, 2002).

Digitally Programmable Analog Instrument

The digitally programmable analog instrument (DPA), or hybrid, hearing instrument is a slightly more advanced hearing aid than the conventional analog hearing aid. This instrument has the same basic components as the analog hearing aid with a microphone, an amplifier and a receiver that all function in basically the same manner as with the conventional analog instrument. However, this hearing aid differs from the conventional hearing aid in that it typically contains a memory chip, not a potentiometer, where the selected settings are stored (Hussung & Hamill, 1990). Therefore, the frequency response, gain, maximum output, and compression parameters of the hearing aid are set by attaching the hearing aid to a computer or other digital device, rather than setting the trimpots with manual screwdriver adjustment (Hussung & Hamill, 1990).

Another advanced function in some digitally programmable analog hearing aids is their ability to store multiple memory programs (multiple sets of electroacoustic characteristics) by utilizing the previously mentioned memory chip. Therefore, one program can be set for normal listening situations, one program can be set for noisy listening situations and yet another program can be set for telephone listening situations. The philosophy behind multiple memories is that different sets of amplification parameters are appropriate for different listening environments, and the hearing aid user should be given the freedom to decide when to use the various options (Hussung & Hamill, 1990).

There are many different advantages and disadvantages of digitally programmable analog hearing aids. One advantage is greater electroacoustic flexibility resulting in greater comfort and sound quality (Dillon, 2001). Another advantage is the potential utilization of remote controls, enabling easier operation of the volume control, multiple programs for different listening needs, and simultaneous operation of two volume controls (Dillon, 2001). One limitation of the digitally programmable analog hearing aid is that the sophistication and flexibility of its signal processing algorithms are substantially less than with fully digital signal processing systems, which places limitations on the amount of adjustment that can be made with this instrument (Hussung & Hamill, 1990).

Fully Digital Signal Processing Instrument

The fully digital signal processing (DSP) hearing aid, similar to conventional analog and digitally programmable analog instruments, contains a microphone, an amplifier, and a receiver. However, between the microphone and the amplifier is an analog-to-digital converter and between the amplifier and receiver is a digital-to-analog converter. The microphone of a fully digital hearing aid, similar to a conventional analog or digitally programmable analog hearing aid, picks up pressure variations produced by moving molecules in the environment, which causes the diaphragm of the hearing aid microphone to have an analogous motion, thereby converting acoustic signals into electric signals (Katz, 2002). In order to convert the electric signals into digital signals an analog-to-digital converter produces a digital representation of the signals by sampling the electric signals at discrete points along the waveforms and assigning numbers (1's and 0's) to represent the voltage amplitudes at specific points in time (Hussung & Hamill, 1990). Each 1 or 0 is referred to as a binary digit, or bit, which is the most fundamental unit used by a computer (Mendel, 1999).

There are two major factors that affect the accuracy of the digital representation of the waveform and one of these factors is the sampling rate. The sampling rate refers to the number of samples taken per second or how often the waveform amplitude is measured and the analog-to-digital conversion is performed (Hussung & Hamill, 1990). The nyquist theorem is used to determine how fast to sample a signal without missing relevant frequency information (Hussung & Hamill, 1990). This theorem states that the sampling rate must be at least twice the highest frequency of interest in the input signal. Therefore, if representation was needed for a 5,000 Hz frequency, the sampling rate must be at least 10,000 Hz in order to fully represent the signal.

When the sampling rate is not high enough to represent higher frequencies accurately, they may appear in the signal as lower frequencies when sampled, which introduces erroneous components into the signal (Hussung & Hamill, 1990). This addition of new low frequency information into the sampled signal is termed "aliasing" and can be eliminated by the addition of an antialiasing, or low-pass filter (Katz, 2002). This antialiasing filter eliminates frequencies greater than the Nyquist frequency so that they do not appear as aliases in the sampled waveform (Hussung & Hamill, 1990).

The other major factor that affects the accuracy of the digital representation of the waveform is the step size, which determines the amplitude resolution of the signal. Therefore, not only is the signal sampled at discrete times, but the amplitude level of the signal is described using discrete steps (Hussung & Hamill, 1990). In order to describe the amplitude of the signal, the incoming analog voltage range is divided into steps and all the values within each step are grouped together and, for each sampled point, a digital value is assigned that corresponds to the appropriate region (Hussung & Hamill, 1990). This conversion process is termed quantization and involves the translation of the amplitude of the signal into binary digits (bits) (Katz, 2002). When more bits are used, the voltage resolution is finer and the waveform more accurately represents the input signal (Hussung & Hamill, 1990). However, no matter how many bits are used, there is always a difference between the converted value and the actual value. The difference between these two values is called quantization error and may result in the addition of noise into the signal. In a well-designed system, however, this error is sufficiently small and will be inaudible in the final output (Hussung & Hamill, 1990).

Once signals entering the hearing aid system are converted by the analog-to-digital converter into digital form, they are then sent to the microprocessor for further manipulation. The microprocessor is a computer program, which is comprised of one or more algorithms (a list of rules or instructions for processing the input signal) (Hussung & Hamill, 1990). Filtering, feedback reduction, multiband compression, noise reduction, and speech enhancement are types of algorithms that might be accomplished by the microprocessor (Hussung & Hamill, 1990).

Once the microprocessor has finished manipulating the signal utilizing its many algorithms, the digital-to-analog converter converts the signals back into an analog form. This process is the reverse of the analog-to-digital conversion discussed earlier. As in the analog-to-digital process, a mapping occurs between a digital value and an analog voltage (Hussung & Hamill, 1990). Because of this mapping, the signal jumps from one value to the next, rather than changing gradually, which can introduce erroneous high frequency energy or "images" into the signal (Hussung & Hamill, 1990). These high frequency components are values that occur above the Nyquist frequency and in order to eliminate them from the signal a low pass or anti-imaging filter is used (Katz, 2002). Once the digital-to-analog transformation is complete, the electric signal is then sent to the hearing aid receiver where it is changed into an acoustic form ready to be delivered to the ear.

Fully digital signal processing hearing aids have many advantages over both the conventional analog and digitally controlled analog hearing instruments. The biggest advantage is that they can perform more complex processing than is possible in analog or hybrid hearing aids (Dillon, 2001). Fully digital signal processing hearing aids are also able to make decisions about how to process the sound, depending on what they sense the overall acoustic environment to be (Dillon, 2001). Finally, as technology advances, the physical size and power consumption of these digital circuits will continue to decrease, leaving the hearing aid user with a smaller more powerful instrument (Dillon, 2001).

Hearing Aid Comparison Studies

As discussed earlier, there are currently three different types of hearing aids available for individuals with hearing impairments. These three different amplification instruments include the conventional analog hearing aid, the digitally programmable analog hearing aid and the fully digital signal processing hearing aid. Within the past decade, researchers in the field of audiology have performed numerous studies comparing these three types of hearing aids based on hearing aid performance, hearing aid benefit, and user preference in order to judge which hearing device is superior.

One of the earlier hearing aid comparison studies was performed by Benson, Clark, and Johnson (1992). In this study, the Resound ED2 digitally controlled analog hearing aid was compared with various conventional linear and automatic gain control nonprogrammable hearing aids previously worn by the subjects who participated in the study. Performances of the different hearing aids were assessed by functional gain testing, dynamic range measurement, real ear measurement and by evaluating the subject's own subjective benefit of the hearing aids using a questionnaire developed by the research team. Results from this study showed overall favor for the Resound ED2 hearing aid over the subject's previously worn hearing aids. Lower aided thresholds and higher loudness discomfort levels (LDLs) were noted resulting in broader dynamic ranges of listening comfort. Furthermore, based on a questionnaire given to subjects comparing the different hearing aids on a rating scale of one to seven with seven being the best score, subjects rated hearing aid performance higher with the Resound ED2 in all listening situations assessed than with their own conventional analog instruments.

One limitation of the Benson et al. (1992) study is that performance differences between the different hearing aid technologies could be due to subject comparisons between linear circuitry and compression circuitry instead of subject comparisons between conventional analog hearing aids and digitally controlled analog hearing aids. Another limitation to this study is that twelve out of the total eighteen subjects participating in the study were previously monaural hearing aid users. This is problematic because subjects in this study were not only comparing the different hearing aid technologies, but they were also comparing the difference between using one hearing aid as opposed to using two hearing aids. There have been numerous studies performed comparing the differences between being fit with one hearing aid vs. being fit with two hearing aids and the majority of these studies have shown both objective and subjective benefit for using two hearing aids as opposed to using just one.

A similar study to the Benson et al. (1992) study performed more recently in 1999 by Humes, Christensen, Thomas, Bess, Hedley-Williams and Bentler also compared the aided performance and benefit provided by a linear conventional hearing aid and a two-channel WDRC (Wide Dynamic Range Compression) digitally controlled analog hearing aid. This study utilized fifty-five individuals with sensorineural hearing losses ranging from mild to severe. Outcome measures of this study included aided performance and objective benefit in quiet and in noise at a variety of different speech levels (50, 60, 75 dB SPL), at various levels of babble background (quiet, signal-to-babble levels of +5 and +10) and for various types of test materials (monosyllabic words and sentences in connected speech). Subjective measures of aided performance (sound quality judgments and magnitude estimates of listening effort) and relative benefit (improvement in listening effort and Hearing Aid Performance Inventory, HAPI (Cox & Gilmore, 1990)) were also obtained. Results from this study showed that although both types of hearing aids demonstrated significant benefit, the WDRC digitally controlled analog instruments were superior to the conventional linear devices for many of the outcome measures. The limitations to this study are very similar to the Benson et al. (1992) article mentioned previously with the exception of the monaural to binaural comparison.

Once the fully digital signal processing hearing instrument was developed, the question began to emerge as to which technology, conventional analog vs. fully digital digital signal processing, offered better aided performance and clearer sound quality. In 1998, shortly after the first fully digital signal processing hearing aid products were made available to the hearing aid consumer, Valente, Fabry, Potts, and Sandlin (1998) performed a study comparing the conventional analog hearing aid to the fully digital signal processed hearing aid. In this study, the Widex Senso C8 (behind-the-ear hearing aid) and the Widex Senso CX (in-the-ear hearing aid) hearing aids using fully digital signal processing technology were compared to the participating subjects' current conventional analog hearing aids. Objective test results from this study failed to demonstrate significant differences in performance between the Widex Senso hearing aids and the subject's own hearing aids. However, subjective measures obtained from this study indicated a preference for the Widex Senso hearing aids over the subject's own conventional analog hearing aids.

Following the previously mentioned study, Valente, Sweetow, Potts, and Bingea (1999) compared two different Windex Senso behind-the-ear hearing aids to the subject's own hearing aids. In this study the hearing aids utilized were the Widex Senso C8 (omnidirectional only) hearing aid, the Widex Senso C9 (directional only) hearing aid, and the subject's own previously worn conventional analog hearing aids (a mixture of compression and linear instruments). Differences in performance between the C8, C9 and the subject's own hearing aids were assessed using the Speech Perception in Noise (SPIN) (Bilger et al., 1984) test administered at +7, 0 and -7 dB signal-to-noise ratio (SNR) with the noise fixed at 65 and 75 dB SPL. Also, a questionnaire (developed by the research team) rating subject preference between the C9 instrument and the subject's own conventional analog hearing aids was completed. Results from this study showed in all test conditions the C9 hearing aid to be superior when compared to the C8 hearing aid and the subjects own hearing aids. Also, as the SNR became more difficult, the C9 hearing aid showed a greater advantage over the other hearing instruments utilized in the study. Significant differences were not present between the C8 hearing aid and the subject's own hearing aids. Finally, the questionnaire utilized in this study showed a statistically significant preference for the C9 hearing aid in comparison to the subject's own hearing aids.

It was not surprising that the C9 instrument performed better in noise than the C8 instrument due to the directionality provided by the dual-microphones incorporated in the C9 hearing aid. Furthermore, Valente et al. (1998) attributed the lack of objective measurable difference between the Widex Senso C8 hearing aid to the subjects own hearing aids to be due to the inability of a testing environment, equipped with controlled acoustics, to mimic a real world listening situation.

Another study performed by Bille, Jensen, Kjærbøl, Vesterager, Sibelle, and Nielsen (1999), similar to the Valente et al. (1999) study discussed previously, compared the Widex Logo L8, a digitally programmable analog hearing aid with the Widex Senso C3, a fully digital signal processing hearing aid. This study utilized 25 experienced hearing aid users with sensorineural hearing losses within the hearing level target of the test hearing aids. Outcome measures utilized in this study were improvements in speech recognition score in noise, overall performance, overall satisfaction, and various measures of hearing aid performance evaluated by a self-assessment questionnaire designed by the research team. Results from this study showed no significant differences in outcome measures, both objective and subjective, between the Widex Logo L8 and the Widex Senso C3 hearing aids. One limitation to this study is that it failed to take into consideration the specific features of each subject's hearing loss such as severity and configuration differences. This lack of consideration could have impacted the quality of fine tuning of the digital hearing aid and thus negatively impacted the subjects' own assessment of the digital instruments.

Once digital technology was readily accepted by the hearing aid industry, many different hearing aid manufacturers began to produce their own product lines of the fully digital signal processed instruments. A study performed by Knebel and Bentler (1998) compared two fully digital signal processing hearing aids, the Oticon DigiFocus hearing aid and the Widex Senso hearing aid. Both of the previously mentioned hearing aids have different philosophies of design and fitting strategies, therefore, it was hypothesized by the researchers that there would be noticeable differences between the two amplification instruments. Both objective and subjective tests were performed on each of the hearing aids. Objective procedures for this study included real ear measurements, the Speech In Noise (SIN) Test (Killion & Villchur, 1993), the Hearing In Noise Test

(HINT) (Soli & Nilsson, 1994), and the CUNY Sentence Test (Levitt & Neuman, 1990). Subjective tests for this study included the Abbreviated Profile of Hearing Aid Benefit (APHAB) (Cox & Alexander, 1995), the Attitudes Towards Loss of Hearing Questionnaire (ALHQ) (Saunders & Cienkowski, 1996), the Glasgow Benefit Inventory (GBI) (Robinson, Gatehouse, & Browning, 1996), and an exit questionnaire/interview designed by the research team. Results from this study showed that although the Oticon DigiFocus and the Widex Senso hearing aids utilize different signal processing and fitting strategies, the subjective and objective outcome measures of this study revealed no significant differences between the two amplification devices.

One limitation to the Knebel & Bentler (1998) study is the difference in the sophistication of the programming of the Oticon and Widex hearing aids. The Oticon DigiFocus hearing aids were programmed using a fitting program displayed on a computer allowing greater manipulation of the frequency response of the hearing aid, while the Widex Senso hearing aids were programmed using a small portable programmer limiting the manipulation of the frequency response of the hearing aid. Another limitation to this study is that many of the subjects in this study were not satisfied with their current conventional analog hearing aids possibly due to the age or inappropriateness of fit of their own hearing aids, which could have influenced their assessment of the fully digital signal processing hearing aids.

In 1998, a study comparing all three different hearing aid technologies was performed by Newman and Sandridge. In this study a linear analog hearing aid, a two-channel non-linear hearing aid (WDRC in the low frequencies and linear amplification in the high frequencies) and a fully digital signal processing hearing aid were utilized.

Subjects participating in this study were blinded to the type of hearing aid technology they were wearing during the course of the study. Objective measurements including the SPIN (Bilger, Neutzel, Rabinowitz, & Rzeczkowski, 1984), the Audibility Index (AI) (Killion, Mueller, Pavlovic & Humes, 1993; Mueller & Killion, 1990) and subjective measures including the APHAB (Cox & Alexander, 1995), the Hearing Handicap Inventory (HHIE) (Ventry & Weinstein, 1982), a daily log and preference ratings were used in comparing the three different hearing aid instruments. The only significant difference between the different hearing aids shown in this study was on the SPIN test, where subjects performed better utilizing the digital technology. A cost-effectiveness analysis was also included in this study, which showed the linear devices to be the most cost-effective; however, the majority of the participants in this study indicated a preference for the fully digital signal processing instruments.

Recently, a study performed by Bentler, Niebuhr, Johnson and Flamme (2003) looked at the affects of labeling on subject assessment of hearing aids. Two groups of subjects participated in this study. Group A subjects were fit with two different sets of digital signal processing hearing aids over the course of two months, while group B subjects were fit with one set of digital signal processing hearing aids over the course of two months (group B subjects were falsely instructed that their hearing aids would be changed at the end of one month). Both groups were told that they would be wearing one set of digital signal processing hearing aids for one month and one set of conventional analog hearing aids for one month. Both objective and subjective measures including probe microphone measurements, The Hearing In Noise Test (HINT) (Soli & Nilsson, 1994), The CUNY Sentence Test (Levitt & Neuman, 1990), The Abbreviated Profile of

Hearing Aid Benefit (APHAB) (Cox & Alexander, 1995), The Glasgow Benefit Inventory (GBI) (Robinson, Gatehouse, & Browning, 1996), Client Oriented Scale of Improvement (COSI) (Dillon, James, & Ginis, 1997), and an exit questionnaire/interview developed by the projects researchers, were taken from subjects at the completion of one month and at the completion of the second month of the study. Results from this study showed significant labeling effects (where subjects are more inclined to have a preference for a hearing aid technology that they are told is more sophisticated) for many of the outcome measures indicating the need for double-blinding in studies assessing the effectiveness of new technologies.

Finally, a study performed by Adams (2000) similar to the Newman and Sandridge study (1998) looked at a comparison of hearing aid technology in school-age children. In this study three different hearing aid technologies (conventional linear, digitally programmable analog and fully digital signal processing) were compared. A total of nine subjects participated in this study and each subject utilized each hearing aid technology for a period of approximately three to four weeks. Objective measurements taken in this study included functional gain measurements, insertion gain measurements, audibility index measurements, and word recognition measurements in quiet. Subjective measurements taken in this study included the Abbreviated Profile of Hearing Aid Performance (APHAP) (Cox & Alexander, 1995), the Listening Inventory for Education (LIFE) (Anderson & Smaldino, 1997), the Client Oriented Scale of Improvement (COSI) (Dillon, James, & Ginis, 1997) and an exit interview including questions developed by the researcher. Results from this study showed that objectively all three hearing aid technologies performed about the same in a controlled test environment, however subjects demonstrated a subjective preference for the fully digital signal processing technology, which could have been due to significant labeling effects similar to results noted in the Bentler et al. (2003) study.

The results seen in the Adams (2000) study are very similar to others found in previous research. Results comparing different hearing aid technologies such as conventional analog, digitally programmable analog and fully digital signal processed technology often show little difference in objective measures when the hearing aids are fit appropriately. This lack of difference may be due to the controlled testing environment in which the measurements are taken. However, subjective measurements in these studies often show a subjective preference for the fully digital signal processing technology indicating clearer sound quality and better noise reduction abilities. Because of the lack of research comparing different hearing aid technologies in everyday listening situations it is hard to distinguish which hearing aid technology, conventional analog or fully digital signal processing, is truly superior.

Summary

The ability to hear well is one of the most important aspects of a child's life. As previously stated, if a hearing impaired child's hearing loss remains undetected and untreated, it may lead to delayed speech and language development, social and emotional problems, and possible academic failure. Furthermore, with so many different hearing aids to choose from on the market today and with so many different factors playing a role in which hearing aids are chosen for hearing-impaired children, numerous possibilities exist as to what types of hearing aids hearing healthcare professionals are providing for their pediatric patients. The present study sought to address the question of what types of hearing aid technology are school-aged children wearing in school districts located within the state of Ohio and is the fitting pattern seen by this state consistent with national hearing aid sales statistics reported from all hearing aid manufacturers.

CHAPTER 3

METHODOLOGY

The purpose of this study was to identify the current hearing aid technology fitting patterns of school-aged children throughout the state of Ohio in order to learn what types of hearing aid technology these children are wearing, to determine what the fitting patterns of these different hearing aid instruments are in various regions throughout the state and to compare Ohio state statistics to national sales statistics reported from hearing aid manufacturers throughout the United States. The present study was accomplished by contacting educational audiologists working in both Ohio school systems and Special Educational Regional Resource Centers (SERRC Centers) located throughout the state of Ohio. These educational audiologists were asked to complete a survey regarding the hearing aid technology currently worn by children in their caseloads. This chapter discusses the methodology implemented in this study and includes a description of the subjects, procedures, and data analysis used.

Subjects

The subjects who participated in this study were school-aged children currently using personal hearing instruments. Each participant in this study is enrolled in a school district located in the state of Ohio and is associated with an educational audiologist in that school district.

Procedures

Data for this study were collected by contacting educational audiologists employed by the school systems and Special Educational Regional Resource Centers (SERRC Centers) throughout the state of Ohio via email, letter, and phone. The first method of contact utilized in this study was email. A general letter (appendix A) was sent to all educational audiologists in the state of Ohio via the Ohio audiology listserv accessed through the email address of audnet@LEECA.org. A general letter (appendix B) was also sent to all the SERRC Centers throughout the state of Ohio via the on-line directory accessed through the web site of www.orclish.org. The second method of contact utilized in this study was by formal letter (appendix A and appendix B) through postal mail. The addresses of the educational audiologists in the state of Ohio were listed on the Ohio audiology listserv and the addresses of the SERRC Centers were listed on the web site www.orclish.org. The final method of contact utilized in this study was by telephone. The telephone numbers of the educational audiologists participating in this project were listed on the audiology listserv and the phone numbers of the SERRC Centers were listed on the web site www.orclish.org.

Both the general letters sent by email and the formal letters sent by postal mail requested information regarding the school-aged children in the school districts of the educational audiologists. The information requested included the number of children wearing either conventional analog, digitally programmable analog or fully digital signal processing hearing aid technology, the age ranges of the children sampled, the school districts in which the children were located, and the number of children fit monaurally (one hearing aid) and binaurally (two hearing aids). No information on the particular subjects sampled in this study such as names, addresses and telephone numbers were exchanged.

The educational audiologists participating in this study were able to respond to the survey by email, letter, or telephone. The deadline given to the educational audiologists and SERRC Centers to submit their pediatric hearing aid information was November 30, 2003. Furthermore, fourteen out twenty-eight surveys that were sent out were returned by the November 30th deadline.

Data Analysis

Once the survey data for the present study was collected, it was divided geographically by Ohio region (Northeastern Ohio, Central Ohio, Southwestern Ohio, Southern Ohio and Eastern Ohio). Furthermore, within those individual geographic regions the data was categorized by hearing aid technology (Conventional Analog, Digitally Programmable Analog and Fully Digital Signal Processing). This method of categorization was implemented in order for investigators too not only be able to identify the overall hearing aid technology fitting pattern for the state of Ohio, but to compare the data based on geographical region in order to identify the existence of significant differences in fitting patterns within the individual Ohio regions.

The data analysis that was used in the present study to identify significant differences in hearing aid technology fitting patterns among the five different Ohio regions sampled was a Pearson Chi-Square Test of Association for Comparing Entire Distributions. Further Chi Square testing was performed in order to compare the Ohio state data as a whole to hearing aid sales statistics from the years of 2002 and 2003 reported from the Hearing Industries Association (HIA), which is an organization that collects hearing aid sales statistics from all hearing aid manufacturers in order to assess hearing aid sales trends from year-to-year.

CHAPTER 4

RESULTS

The present study sought to identify the current hearing aid technology fitting patterns of school-aged children throughout the state of Ohio in order to learn what types of hearing aid technology these children are wearing, to determine the fitting patterns of these different hearing aid instruments in various regions throughout the state and to compare Ohio state statistics to national sales statistics reported from hearing aid manufacturers throughout the United States. This chapter discusses the results of the hearing aid technology survey data. Statistical analyses of the differences across Ohio regions and between state and national data is presented following the presentation of the survey results.

Each of the following pie charts shown in this chapter represents a different region in the state of Ohio. These graphs are divided into three sections and each section represents the percentage of children in that region fit with one of three different hearing aid technologies currently available to consumers (conventional analog, digitally programmable analog, and fully digital signal processing).

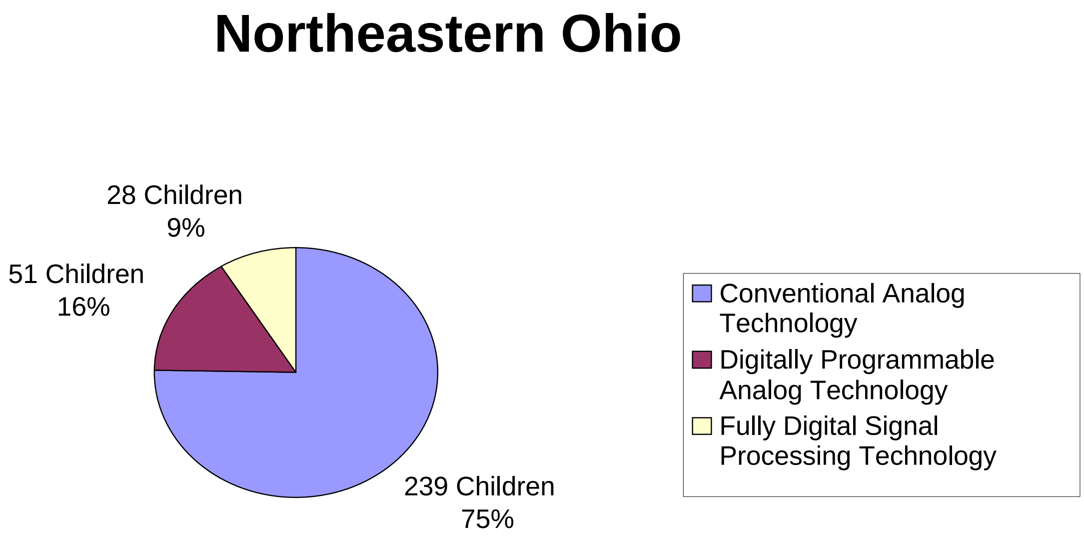

Figure 1: Hearing aid survey data for the region of northeastern Ohio.

Figure 1 is a graph of the hearing aid technology data received from school districts located within the northeastern region of Ohio. In this region seventy-five percent of hearing-impaired children (239 children) utilize conventional analog technology, sixteen percent of hearing-impaired children (51 children) utilize digitally programmable analog technology, and nine percent of hearing-impaired children (28 children) utilize fully digital signal processing technology. This information suggests that most of the hearing-impaired children in the northeastern region of the state of Ohio are wearing conventional analog hearing aid technology, while less then a quarter of these children are utilizing either digitally programmable analog or fully digital signal processing technology.

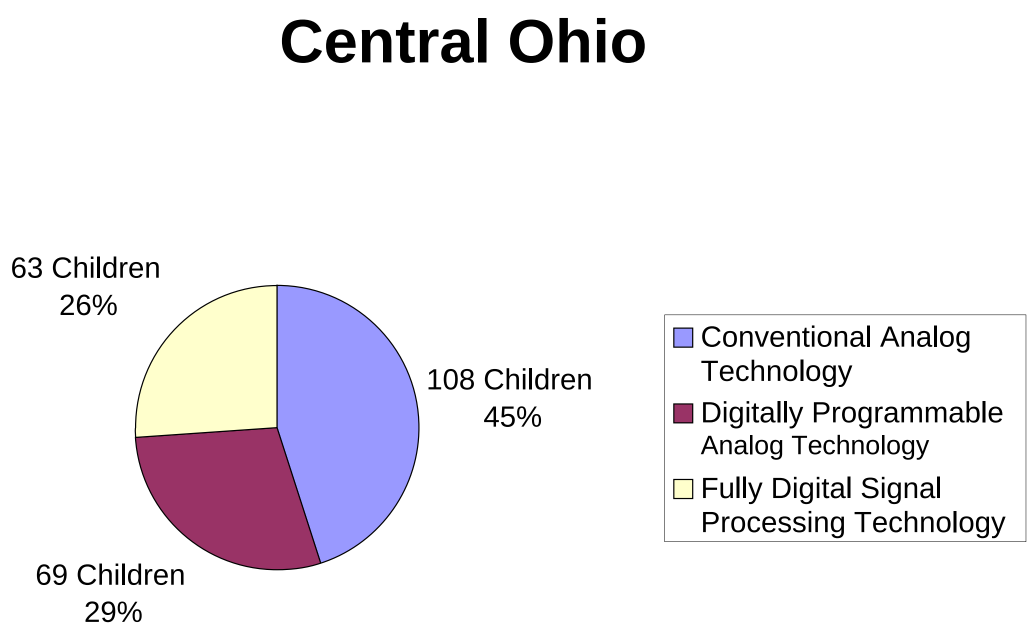

Figure 2: Hearing aid survey data for the region of central Ohio.

Figure 2 shows hearing aid technology data received from school districts located within the central region of Ohio. In this region forty-five percent of hearing-impaired children (108 children) utilize conventional analog technology, twenty-nine percent of hearing-impaired children (69 children) utilize digitally programmable analog technology, and twenty-six percent of hearing-impaired children (63 children) utilize fully digital signal processing technology. This information suggests that almost half of hearing-impaired children enrolled in central Ohio school districts are wearing conventional analog technology, while slightly more than half of these children are wearing either digitally programmable analog or fully digital signal processing technology.

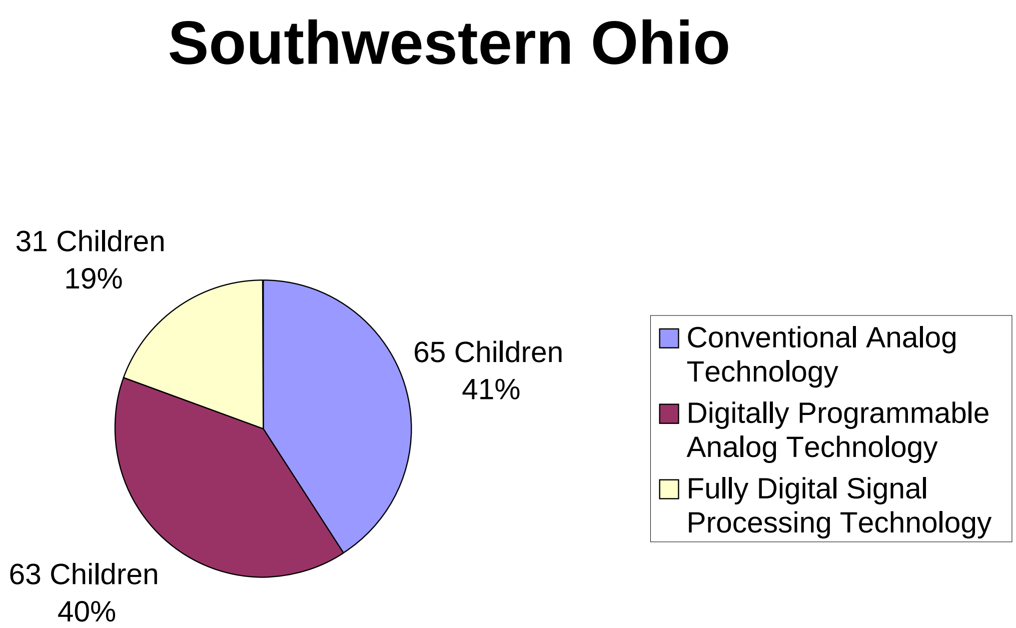

Figure 3: Hearing aid survey data for the region of southwestern Ohio.

Figure 3 is a graph of the hearing aid technology data received from school districts located within the southwestern region of Ohio. In this region forty-one percent of hearing-impaired children (65 children) utilize conventional analog technology, forty percent of hearing-impaired children (63 children) utilize digitally programmable analog technology, and nineteen percent of hearing-impaired children (31 children) utilize fully digital signal processing technology. This information suggests that there are almost as many hearing-impaired children utilizing conventional analog technology as there are hearing-impaired children utilizing digitally programmable analog technology in this Ohio region. Furthermore, less than a quarter of these children are wearing fully digital signal processing technology.

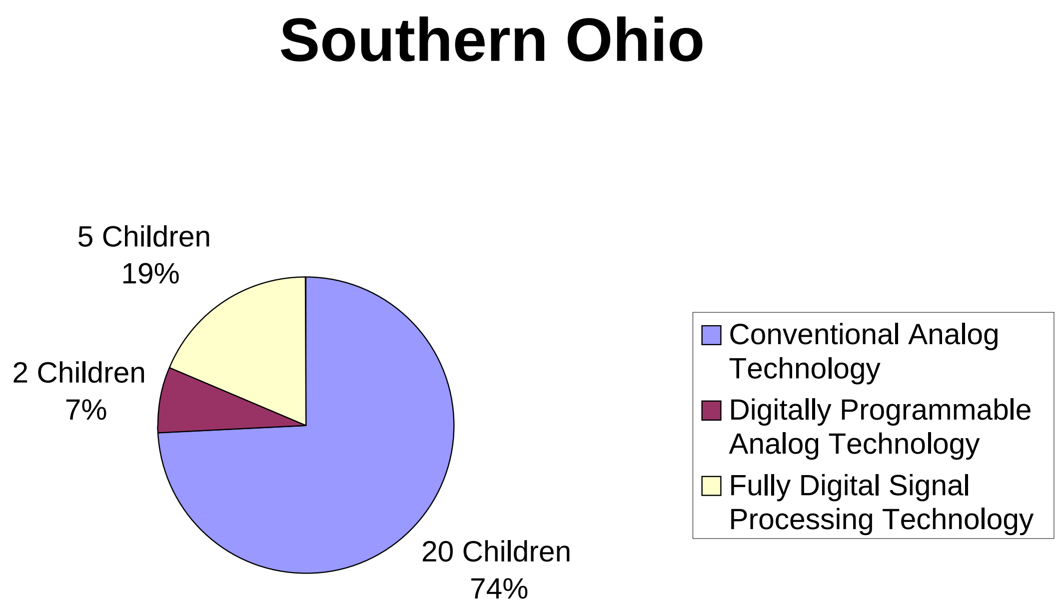

Figure 4: Hearing aid survey data for the region of southern Ohio.

Figure 4 shows hearing aid technology data received from school districts located within the southern region of Ohio. In this region seventy-four percent of hearing-impaired children (20 children) utilize conventional analog technology, seven percent of hearing-impaired children (2 children) utilize digitally programmable analog technology, and nineteen percent of hearing-impaired children (5 children) utilize fully digital signal processing technology. This information suggests that most of the hearing-impaired children in the southern region of the state of Ohio are wearing conventional analog technology. However, there are more hearing-impaired children utilizing fully digital signal processing technology than there are hearing-impaired children utilizing digitally programmable analog technology.

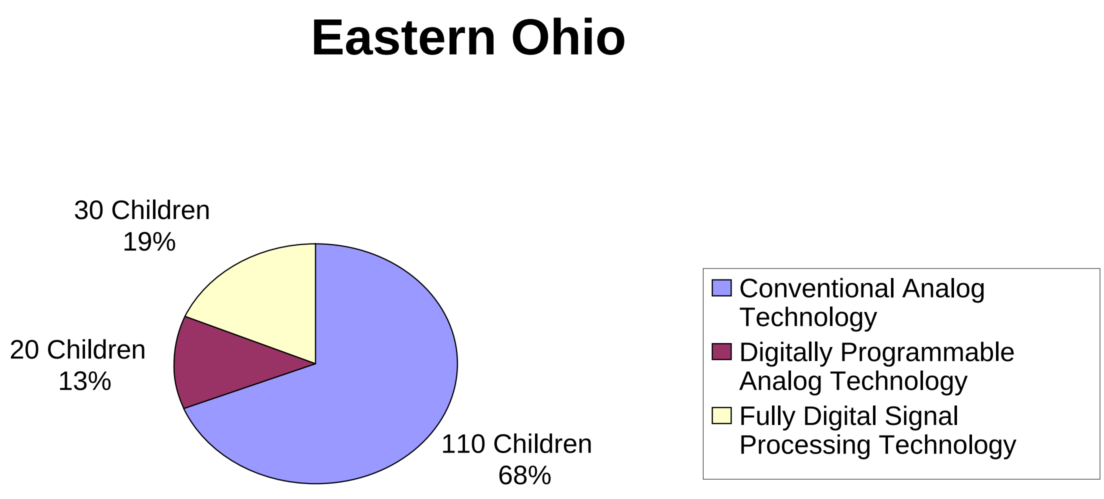

Figure 5: Hearing aid survey data for the region of eastern Ohio.

Figure 5 is a graph of the hearing aid technology data received from school districts located within the eastern region of Ohio. In this region sixty-eight percent of hearing-impaired children (110 children) utilize conventional analog technology, thirteen percent of hearing-impaired children (20 children) utilize digitally programmable analog technology, and nineteen percent of hearing-impaired children (30 children) utilize fully digital signal processing technology. This information is very similar to the data received from the southern region of Ohio and suggests that most of the hearing-impaired children in the eastern region of the state of Ohio are wearing conventional analog hearing aid technology, with more of these children utilizing fully digital signal processing technology than programmable analog technology.

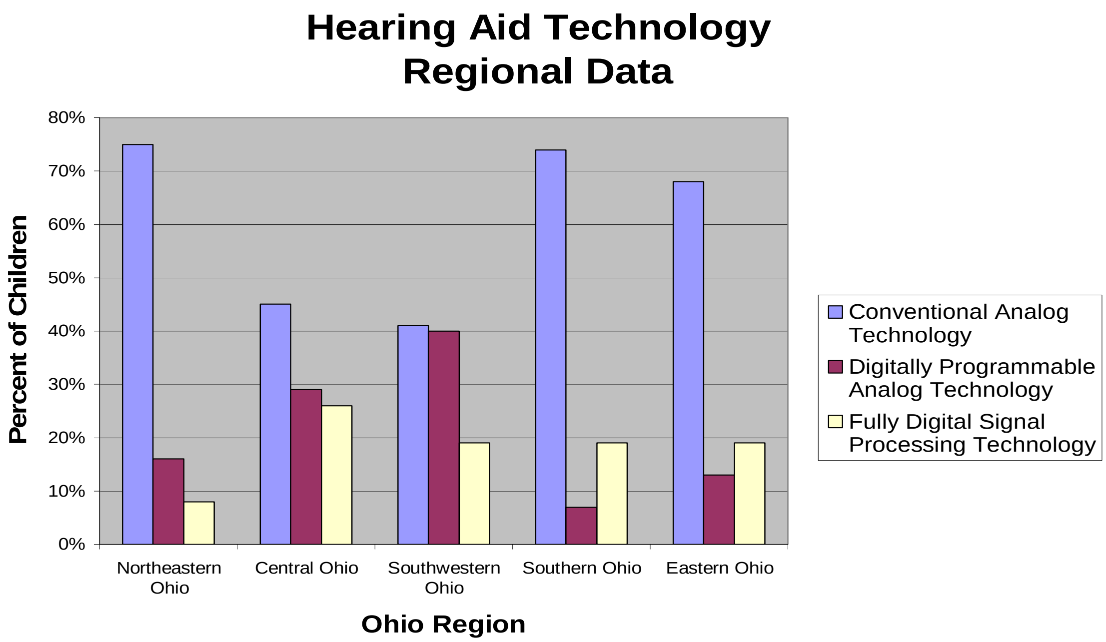

Figure 6: Comprehensive graph of hearing aid survey data for the state of Ohio.

Figure 6 is a comprehensive graph of the hearing aid technology data for every Ohio region previously discussed. The most noticeable trend depicted in this comprehensive graph is that for each of the five different Ohio regions the most commonly worn technology is the conventional analog hearing aid technology. Furthermore, the second most commonly worn technology in the northeastern, central, and southwestern regions of Ohio is the digitally programmable analog technology with the fully digital signal processing technology being the least commonly worn technology for those three regions. In the southern and eastern regions of Ohio the second most commonly worn technology is the fully digital signal processing technology followed by the digitally programmable analog technology. It should be noted that the data provided for southern Ohio represents significantly fewer children when compared to each of the remaining four regions in Ohio.

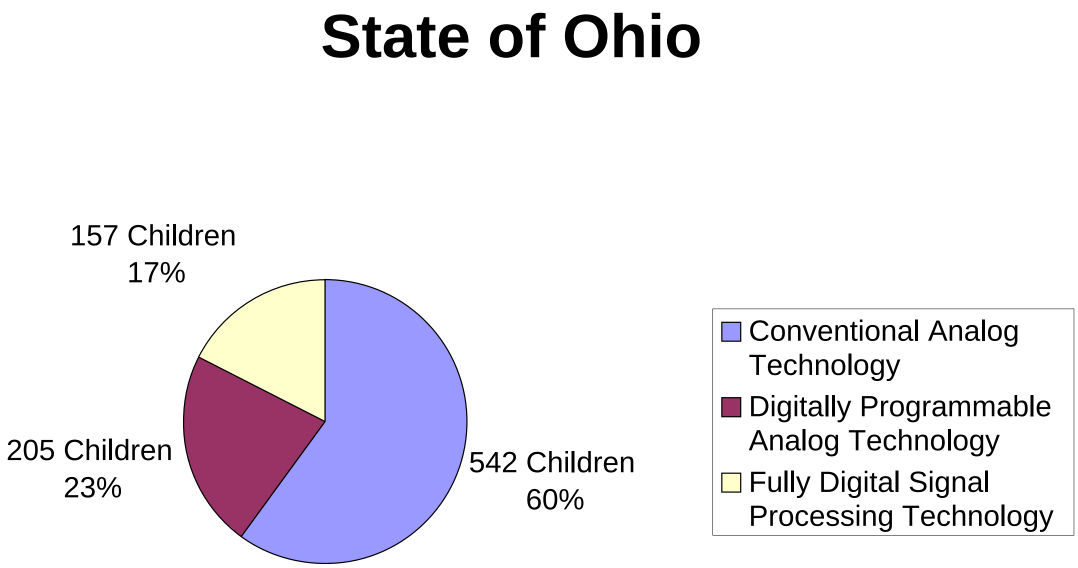

Figure 7: Hearing aid survey data for the State of Ohio.

Figure 7 is a comprehensive graph of the previously discussed survey information, which shows the hearing aid technology data received from all the school districts located within the state of Ohio. In the state of Ohio sixty percent of the children surveyed (542 children) utilize conventional analog technology, twenty-three percent of the children surveyed (205 children) utilize digitally programmable analog technology, and seventeen percent of the children surveyed (157 children) utilize fully digital signal processing technology. This information suggests that more than half of the hearing-impaired children in the state of Ohio are wearing conventional analog technology, while less than a quarter of these children are wearing digitally programmable analog technology. Furthermore, fully digital signal processing technology is the least commonly worn technology when comparing all three hearing aid technologies together.

A Pearson Chi-Square Test of Association for Comparing Entire Distributions was conducted in the present study to identify existing differences in hearing aid technology fitting trends among the five different Ohio regions sampled (Northeastern Ohio, Central Ohio, Southwestern Ohio, Southern Ohio, and Eastern Ohio). The results of this test were significant, χ^2 (8, N=904) = 99.07, p<.01, suggesting that there are significant differences in fitting patterns of hearing aid technology associated with the different Ohio regions sampled in this study.

Further Chi Square testing was conducted in this study in order to compare the Ohio state hearing aid technology survey data from the 2002-2003 school year to national hearing aid sales data reported by the Hearing Industries Association (HIA) for the years of 2002 and 2003. To perform this analysis, obtained data from this study collected from the hearing aid surveys for the state of Ohio (Sample Table Appendix C) was compared with the expected data for the state, which was based on the HIA national hearing aid sales percentages for each year (National Sales Statistics Table Appendix C). Results from the Chi Square analyses comparing state versus national data (one analysis for each hearing aid sales year) were significant showing that the Ohio state fitting pattern identified from the present study is significantly different when compared to national hearing aid sales statistics reported from HIA for the years of 2002, χ^2 (2, N=904) = 401.1, p<.01 and 2003, χ^2 (2, N=904) = 957.87, p<.01.

CHAPTER 5

DISCUSSION

Hearing aids, in some form or another, have been on the market for many years. The first commercially available “hearing aids” appeared in the 1800’s and included a wide array of different amplification products such as acoustic urns, ear trumpets, acoustic hat devices and speaking tubes. However, it wasn’t until the 1890’s that the first electric hearing aid, developed by Alexander Graham Bell, appeared on the consumer market and from that point on many great advancements were made in the technology pertaining to hearing aids throughout the twentieth century. These technological advancements, just to name a few, included vacuum tubes, transistors, and fully digital signal processing technology.

Given the many advances that have occurred over the past century, the most influential on the hearing aid sales industry within the past decade has been the introduction of the fully digital signal processing instrument. Based on hearing aid sales reports documented from the Hearing Industries Association (HIA), in 1994 only 6% of the hearing aid sales market consisted of digitally programmable analog instruments while 94% of the hearing aid sales market consisted of conventional analog instruments (Kirkwood, 1999). However in 1998, after the first fully digital signal processing hearing aid products had been on the market for approximately two years, the sales statistics began to change significantly. The hearing aid sales statistics reported from the Hearing

Industries Association in 1998 showed that approximately 68% of hearing aids sold were conventional analog, 24.4% were digitally programmable analog, and 7.6% were digital signal processing (Kirkwood, 2003). Furthermore, the hearing aid sales statistics reported from the Hearing Industries Association in 2002 showed that 31.3% of the hearing aids sold were conventional analog, 27.7% were digitally programmable analog and 42% were fully digital signal processing (Kirkwood, 2003).

The most recent hearing aid technology sales statistics reported from the Hearing Industries Association for the 2003 sales year showed that only 21.5% of the hearing aids sold were conventional analog, 15.2% were digitally programmable analog and 63.3% were fully digital signal processing (Kirkwood, 2004). These data suggest that in years to come the entire hearing aid sales market will only include fully digital signal processing devices. Therefore, future research pertaining to hearing aids will include high end fully digital signal processing products to low end digital signal processing products, and the conventional analog and the digitally programmable analog hearing aid technologies will be only a memory from the past.

State Statistics vs. National Statistics

Results from the present study showed that for the 2002-2003 school year 60% of school-age children throughout the state of Ohio are currently fit with conventional analog hearing aid technology, 23% percent of these children are currently fit with digitally programmable analog technology and 17% percent of these children are currently fit with fully digital signal processing technology. Therefore, the overall hearing aid fitting pattern identified for the state of Ohio as a whole reflects that conventional analog technology is the most commonly fit hearing aid technology followed by digitally programmable analog hearing aid technology and then fully digital signal processing hearing aid technology.

In an attempt to compare the obtained Ohio state data previously mentioned to national hearing aid sales statistics reported from the Hearing Industries Association, analysis testing was performed and showed that the hearing aid technology fitting pattern identified for school-age children throughout the state of Ohio differs significantly from the hearing aid technology sales distributions for the United States for the years of 2002 and 2003. The national hearing aid sales statistics showed that fully digital signal processing technology was the most commonly sold hearing aid technology followed by digitally programmable analog hearing aid technology and then conventional analog hearing aid technology, which was exactly opposite of the Ohio state hearing aid technology data, showing that conventional analog technology is the most commonly fit hearing aid technology followed by digitally programmable analog hearing aid technology and then fully digital signal processing hearing aid technology. Given these national statistics, it is interesting to see how the state and national statistics differ suggesting that school-aged children throughout the state of Ohio (wearing some level of hearing aid amplification) are lagging behind the nation in technological advancement pertaining to hearing aid amplification.

The most probable reason for the difference between the Ohio state and national data is that the children from the state of Ohio were obviously wearing older hearing aids at the time the surveys for this study were completed that were purchased before the year 2002, whereas the data collected from the United States was based on hearing aid sales only from the 2002 and 2003 manufacturing years. Therefore, the date of purchase for these instruments would account for the preponderance of conventional analog instruments identified in the present study, especially if these instruments were purchased at the end of the previous decade (1990's).

Another potential reason for the difference between the state and national data is that the Ohio data collected for this study was sampled only from school-aged children whereas the data collected from the United States as a whole was sampled from both adult and pediatric hearing aid users. Therefore, the large differences in both sample size and age distributions within the samples may account for the great differences between distributions from the hearing aid technology data results from both Ohio and the United States.

Finally, another potential reason for the difference between the state and national data is that currently there exists a limitation of financial assistance from Ohio third party affiliates such as Medicaid and the Bureau for Children with Medical Handicaps (BCMH), who on average offer less than $500.00 per each child for hearing services, hearing aids, and hearing aid services. This dollar amount from these two institutions has remained relatively the same for many years despite inflation and the introduction of fully digital signal processing technology to the hearing aid market, both of which have driven most hearing aid prices into the thousands of dollars.

However, no matter what the reasons are for the obvious differences between the state and national statistics, the hearing aid technology fitting patterns for the State of Ohio currently show that the majority of children, who are the most influential of hearing aid users, are still wearing technology that is considered outdated by most experts working in the field of audiology. This issue is very serious considering that the current hearing aid market is moving in a primarily digital direction.

Limitations of the Present Study and Directions for Future Research

Although the present study contributes additional information regarding hearing aid technology relating to pediatric amplification users, investigators of the project recognize that limitations do exist. This study was an attempt at identifying the current hearing aid technology fitting patterns of school-age children throughout the state of Ohio and relating these fitting patterns to national hearing aid sales data reported from the Hearing Industries Association.

One limitation of this study is that data was collected only from the state of Ohio. Therefore, only inferences relating to the state of Ohio could be made regarding hearing aid technology fitting trends and how these fitting trends compare to national hearing aid sales statistics. Future research concerning this specific area should seek to include hearing aid technology fitting data from multiple states due to various differences in socioeconomic status between the different states. The more states included in this type of data research, the closer comparisons can be made with regards to the national sales statistics in order to determine whether hearing-impaired children throughout the nation are moving forward in technological advancements as compared with the Unites States as a whole.

Another limitation of the current study is that data was recorded only from one school year. Future hearing aid technology research similar in procedure to this study should seek to include data collection from multiple years allowing for more detailed comparisons of technology fitting patterns from previous years for both state and national data. Furthermore, if conventional analog technology is eliminated from the hearing aid sales market, future research in this area should address the different levels of fully digital signal processing hearing aid technology from low end technology to high end technology, allowing interested parties the opportunity to assess more accurately the basis behind the hearing aid technology fitting patterns of school-aged children throughout the different states.

A final limitation of the present study is that additional pertinent information could have been included in the hearing aid surveys that were sent to the various audiologists throughout the state of Ohio in order to allow further insights into the data received regarding the hearing aid fitting patterns for the state. Such information could have included identifying the number of years the different audiologist contributing hearing aid information have been practicing in the field, determining the socioeconomic status of the different school districts associated with this study, and finally, reporting the number of years each student sampled had been wearing their hearing aids. Knowing this information could have allowed for more detailed interpretations of the received data and further analysis of the hearing aid fitting patterns identified for the state.

Conclusions

Noting the previously mentioned limitations, the present study did identify the current hearing aid technology fitting pattern for the state of Ohio and determined that as a whole the children that were sampled in this study are clearly lagging behind national trends in technological advancement as it pertains to hearing aid amplification. This information is pertinent because as advancements in hearing aid research continue and the hearing aid market moves in primarily a digital direction, hearing health care professionals, educators and third party affiliates must recognize that the hearing-impaired children wearing these devices must be fit with the best possible technology available in order to aid them in their every day listening environments, therefore allowing them to not be limited by their disability in both their educational and professional careers.

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APPENDIX A

EDUCATIONAL AUDIOLOGISTS LETTER

AND SURVEY

Name: Date

Address:

Dear _________:

I am a graduate student at The Ohio State University currently pursuing my Master's Degree in the field of Audiology. I am performing a research project for my Master's thesis entitled Current Fitting Trends of Different Hearing Aid Technologies in School-Aged Children. In gathering data for this project, I am asking educational audiologists from the state of Ohio to complete the attached survey regarding the school-aged children in their school districts who are currently utilizing hearing aids. Following the completion of this study, I will mail all participants the results. I also plan to present the results of this study at an upcoming OSPEAC or OSLHA conference.

Providing this information will be greatly appreciated and will help in identifying the current hearing aid fitting trends of school-aged children throughout the state of Ohio. I have enclosed a stamped self-addressed envelope for your use. The deadline for submitting this information is July 4, 2003. If you have any questions regarding this study please contact me via telephone at (614) 778-8740 or via email at palumbo.18@osu.edu. I will be contacting you by telephone in the next week to answer any questions that you might have.

Sincerely,

____

Kimberly Palumbo, B.A.

Hearing Aid Technology Survey

1. Name of Audiologist: _______________________

2. School District which you are employed:_______________________

3. How many children wearing hearing aids are in your school district?

   ____
   TOTAL NUMBER

4. What is the age range of the children in your school district? ______________
   AGE RANGE

5. In this total number of children wearing hearing aids, please indicate the following:

   a. The number of children wearing conventional analog hearing aid technology (i.e. non-programmable linear and compression instruments)

      ______________________ ______________________
      Number Wearing Monaural Conventional | Number Wearing Binaural Conventional

   b. The number of children wearing programmable analog hearing aid technology (i.e. linear and compression instruments which are programmable but do not use digital processing of sounds)

      ______________________ ______________________
      Number Wearing Monaural Programmable | Number Wearing Binaural Programmable

   c. The number of children wearing fully digital hearing aid technology (i.e. incorporate digital processing of sounds)

      ______________________ ______________________
      Number Wearing Monaural Fully Digital | Number Wearing Binaural Fully Digital

** If you have a child (or children) fit with hearing instruments that you are not sure how to classify, please indicate the make and model of that instrument below.**

Number of Children	Hearing Aid Manufacturer	Hearing Aid Model
________________	______________________	________________
________________	______________________	________________
________________	______________________	________________

Thank you for your participation in this study.

APPENDIX B

SPECIAL EDUCATIONAL REGIONAL RESOURCE CENTER

LETTER AND SURVEY

Name: Date

Address:

Dear _________:

I am a graduate student at The Ohio State University currently pursuing my Master's Degree in the field of Audiology. I am performing a research project for my Master's thesis entitled Current Fitting Trends of Different Hearing Aid Technologies in School-Aged Children. In gathering data for this project, I am asking educational audiologists from the state of Ohio to complete the attached survey regarding the school-aged children in their case loads who are currently utilizing hearing aids. Following the completion of this study, I will mail all participants the results. I also plan to present the results of this study at an upcoming OSPEAC or OSLHA conference.

Providing this information will be greatly appreciated and will help in identifying the current hearing aid fitting trends of school-aged children throughout the state of Ohio. I have enclosed a stamped self-addressed envelope for your use. The deadline for submitting this information is July 4, 2003. If you have any questions regarding this study please contact me via telephone at (614) 778-8740 or via email at palumbo.18@osu.edu. I will be contacting you by telephone in the next week to answer any questions that you might have.

Sincerely,

____

Kimberly Palumbo, B.A.

Hearing Aid Technology Survey

6. Name of Audiologist: ______________________

7. Location of SERRC Center which you are employed:______________________

8. How many children wearing hearing aids are in your case load?

   ____
   TOTAL NUMBER

9. What is the age range of the children in your case load? _____________
   AGE RANGE

10. In this total number of children wearing hearing aids, please indicate the following:

    a. The number of children wearing conventional analog hearing aid technology (i.e. non-programmable linear and compression instruments)

    _____________________ Number Wearing Monaural Conventional

    _____________________ Number Wearing Binaural Conventional

    b. The number of children wearing programmable analog hearing aid technology (i.e. linear and compression instruments which are programmable but do not use digital processing of sounds)

    _____________________ Number Wearing Monaural Programmable

    _____________________ Number Wearing Binaural Programmable

    c. The number of children wearing fully digital hearing aid technology (i.e. incorporate digital processing of sounds)

    _____________________ Number Wearing Monaural Fully Digital

    _____________________ Number Wearing Binaural Fully Digital

** If you have a child (or children) fit with hearing instruments that you are not sure how to classify, please indicate the make and model of that instrument below.**

Number of Children	Hearing Aid Manufacturer	Hearing Aid Model
_______________	____________________	_______________
_______________	____________________	_______________
_______________	____________________	_______________

Thank you for your participation in this study.

APPENDIX C

HEARING AID TECHNOLOGY TABLES

Sample Table

Region	Hearing Aid Technology			
	Conventional Analog	Digitally Programmable Analog	Fully Digital Signal Processing	**Total**
Northeastern Ohio	239 (75%)	51 (16%)	28 (9%)	**318 (35%)**
Central Ohio	108 (45%)	69 (29%)	63 (26%)	**240 (26%)**
Southwestern Ohio	65 (41%)	63 (40%)	31 (19%)	**159 (18%)**
Southern Ohio	20 (74%)	2 (7%)	5 (19%)	**27 (3%)**
Eastern Ohio	110 (68%)	20 (13%)	30 (19%)	**160 (18%)**
Total	**542 (60%)**	**205 (23%)**	**157 (17%)**	**904**

Frequency Table

Region	Hearing Aid Technology			
	Conventional Analog	Digitally Programmable Analog	Fully Digital Signal Processing	**Total**
Northeastern Ohio	190.66 (60%)	72.11 (23%)	55.23 (17%)	**318 (35%)**
Central Ohio	143.89 (60%)	54.43 (23%)	41.68 (17%)	**240 (26%)**
Southwestern Ohio	95.33 (60%)	36.06 (23%)	27.61 (17%)	**159 (18%)**
Southern Ohio	16.19 (60%)	6.12 (23%)	4.69 (17%)	**27 (3%)**
Eastern Ohio	95.93 (60%)	36.28 (23%)	27.79 (17%)	**160 (18%)**
Total	**542 (60%)**	**205 (23%)**	**157 (17%)**	**904**

National Sales Statistics

As Reported by Hearing Industries Association (HIA)

	2002	2003
Conventional Analog	576,640 (30.3%)	429,385 (21.5%)
Digitally Programmable Analog	527,159 (27.7%)	303,565 (15.2%)
Fully Digital Signal Processing	799,302 (42%)	1,264,189 (63.3%)
Total Number of Hearing Aids Sold Per Year	**1,903,101**	**1,997,139**

State Data Table

	2002-2003 (Obtained)	2002	2003
Conventional Analog	**542 (60%)**	274 (60%)	194 (60%)
Digitally Programmable Analog	**205 (23%)**	250 (23%)	138 (23%)
Fully Digital Signal Processing	**157 (17%)**	380 (17%)	572 (17%)
Total	**904**	904	904